

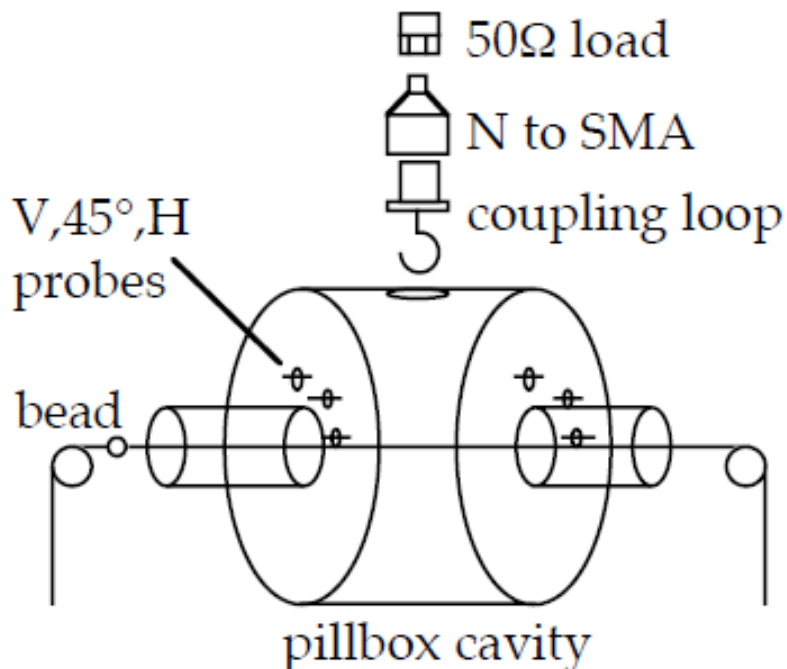
RF Cavity Characterization

Introduction

The experiment is designed to introduce the student to the concept of cavity modes by studying the mode spectrum of a simple model cavity using a network analyzer (NWA). The first few modes are identified by frequency and their Q's measured by a transmission method. For the TM_{010} mode, which would be the accelerating mode in a real cavity, the coupling through a drive loop is determined by means of a reflection measurement and the loaded and unloaded Q's are calculated. The loading of the higher-order modes (HOMs) is also observed and their Q reduction is measured. Finally the longitudinal field profile of the TM_{010} mode is measured using a perturbation method and the shunt impedance is calculated.

Equipment:

- Aluminum model pillbox cavity
- Network Analyzer and calibration kit
- 2 cables
- 2 N-type to SMA adapters
- 2 50Ω SMA loads
- Coupling loop
- E-Field probe
- 1 SMA F-F connector (for Thru calibration)
- Bead-pull apparatus



Transmission Measurement (unloaded cavity)

1. Connect the network analyzer to the probes on each end of the cavity to make a transmission measurement (no coupling loop or damping antenna inserted). Observe Log Mag S_{21} on the NWA, set the frequency range from 700 MHz to 2.3 GHz and adjust the scale so that the resonant peaks in the spectrum are clearly visible (Note: up to 1601 points and an averaging factor of 64 may be necessary to resolve all of the modes with such a wide sweep).
2. Plot the transmission response between the vertical pair of probes on the printer or plotter and save in the NWA memory. Connect the cables to the horizontal pair and compare the data with the memory. Are there any significant differences? Using the marker functions, determine the frequencies of the peaks and compare with the mode frequencies in table 1, which are calculated by a cavity design program (URMEL).
3. Make a table in order of measured frequency identifying each mode with its URMEL counterpart and with additional columns for measurements of unloaded and loaded Q's. Zoom close in on a peak corresponding to a dipole mode and again compare vertical and horizontal spectra.
4. For each peak in turn set the scale, reference value, and frequency span so that the -3.01 dB points can be accurately determined and record the unloaded Q (Q_0) for each mode. Measure the half-power points manually for the first mode, then try using the "widths" function on the NWA for the rest. (Do only for vertical probe pair). 3 dB $10xP_m/P_r$
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Table 1: Mode frequencies calculated by URMEL

Mode Type	Freq (MHz)	R/Q* (Ω)
0E1	786	100.757
1E1	1245	9.761
1M1	1321	0.107
0M1	1417	14.298
2M1	1549	0.000
2E1	1675	0.227
1M2	1705	8.345
0E2	1808	8.004
2M2	2048	0.570
1M3	2104	0.092
0M2	2162	28.562
1E2	2272	0.045

(mode type = aE/Mb where a is the azimuthal order (0=monopole, 1=dipole, etc.), E/M indicates the longitudinal mode symmetry (E=electric boundary condition in midplane, M=magnetic), b=URMEL solution number. *R/Q is calculated on axis for monopole modes and at the beam-pipe radius for higher order modes)

Coupling Measurement

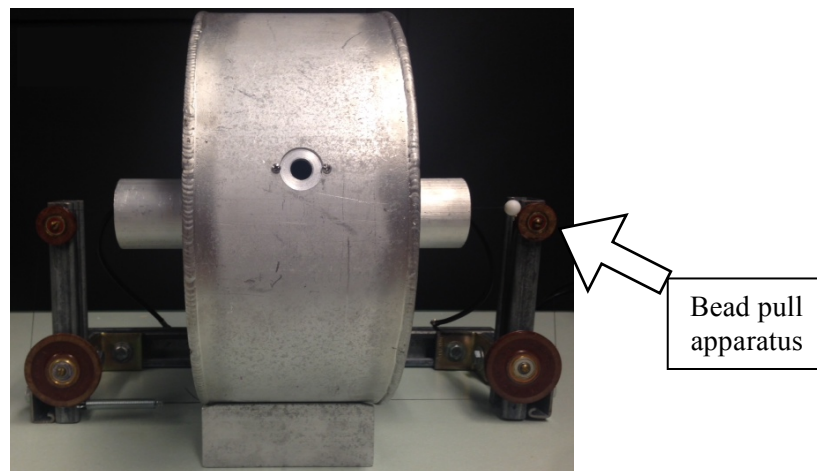
1. Insert the coupling loop, remove the cables from the transmission probes, and connect port 1 of the NWA to the coupler.
2. Observe S_{11} for the TM_{010} (0E1) mode through the range of probe angles from zero to maximum coupling and choose a frequency span that is large enough to accommodate the shift in frequency, but narrow enough to allow good resolution of the resonance curve. Calibrate port 1 of the NWA over this frequency range.
3. Observe the response with calibration turned on for S_{11} or VSWR and on the smith chart as the coupler is rotated. (Note that when using the smith chart, the electrical delay setting on the network analyzer should be adjusted so that the resonant frequency lies on the real axis and the marker mode should be set to real admittance $G+jB$), do this by going to `marker fctn` smith marker menu and then choosing $G+jB$. Then go to `scale ref` electrical delay, and then use the knob to place the marker on the real line of the smith chart.
4. Measure and plot β at resonance as a function of coupler angle. (What variation would one expect from a simple consideration of the loop area coupled to the azimuthal magnetic field?).
5. Determine β_{\max} and the angle for the best match ($\beta=1$). Set the coupler in the matched position and lock in place. Measure β accurately from the $|S_{11}|$ or VSWR curve, calculate the appropriate values for the half-power points for Q_0 and Q_L , and measure the bandwidth at these values. Record the Q_0 and Q_L . Check if $Q_0/Q_L=(1+\beta)$. Does Q_0 measured this way agree with the transmission measurement? Measure Q_0 again from the half-power points on the smith chart and compare.

Loaded Q Measurement

1. Disconnect the cable from the coupler and replace with 50Ω load.
2. Go back to the transmission measurement set-up and re-plot the spectra for the three probe orientations. How are they different from before?
3. Measure the loaded Q's in the Vertical and Horizontal orientations and add them to the table. Calculate the β for each mode. Does the loaded Q of the TM_{010} mode agree with the reflection measurement?

Field Mapping

1. Calibrate the NWA for S11.
2. Connect the port 1 cable to the magnetic coupling loop and insert into the RF cavity at 0° angle. Assemble the bead-pull apparatus around the cavity with the thread running along the central axis and the bead just outside the beam-pipe.
3. Set the **Center** to around 786 and the **Span** to an appropriate value so you can see the peak (20 MHz is a good place to start), and then center the peak using the knob and reset the **Span** to a lower number so the peak is more zoomed in. Set the frequency span so that the peak of the TM_{010} mode is on the right of the display and moves to the left of the display as the bead is pulled to the center of the cavity. This will give acceptable resolution of the frequency shift without having to adjust the display during the measurement (note: some averaging may be required to get an accurate measurement).



4. Measure the frequency and Q_0 with the bead outside the cavity and then proceed to pull the bead through the cavity and make frequency measurements at 0.5 inch intervals (use peak-search tracking on the NWA, do this by going to **Marker fctn** marker search \rightarrow search: **min** and set **widths** on). This should display the bandwidth, the center frequency, the Q factor, and the peak value.
5. Measure again once the bead is out of the cavity on the other side. If the frequency has drifted during the measurement, a linear interpolation can be made between the end

points to correct the data. Tabulate the frequency vs axial position and calculate RT^2/Q and the beam impedance $Z_{||}$ using the spreadsheet provided.

6. If time permits, repeat for the dipole TM_{110} mode with the bead offset close to the wall of the beam pipe at a known radius r . Calculate $Z_{||}(r)$ and Z .

Pillbox Cavities

1. Calibrate the NWA for S11 mode.
2. Connect the SMA cable from port 1 to the full-cell pillbox cavity. Set the **Center** to around 3 GHz and the **Span** to an appropriate value so you are able to see the drastic peak (around 500 MHz is a good reference). Center the peak using the knob and reduce the span in order to zoom into the peak.
3. Store this into memory by going to **Display** Data → Memory. Then detach the cable from the full-cell cavity and attach it to the half-cell. How do you expect the resonance of this cell to compare to the previous resonance measurement? Should the length of the cavity impact the resonance frequency?
4. Compare the two graphs by going to **Display** Data and Memory. Are they similar?
5. Connect the full-cell with the probes to the full-cell cavity with the small diameter hole. Observe the peaks using the same technique as described above. Why is there more than 1 peak?
6. Do the same with the full-cell cavity with the larger diameter hole. How does this resonance peak compare to the others?